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Woltman et al.

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(54) **CHANGING PULSE WIDTH TO REDUCE VISIBLE INTERFERENCE**

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G02B 27/01	(2006.01)
G02B 6/122	(2006.01)
G02F 1/01	(2006.01)
G02F 1/225	(2006.01)

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CPC ***G02B 6/29361*** (2013.01); ***G02B 6/1225*** (2013.01); ***G02B 27/0025*** (2013.01); ***G02B 27/0081*** (2013.01); ***G02B 27/0172*** (2013.01); ***G02F 1/0134*** (2013.01); ***G02F 1/225*** (2013.01); ***H01S 3/0057*** (2013.01); ***H01S 3/0602*** (2013.01); *G02B 2027/0178* (2013.01); *G03B 21/2033* (2013.01)

(58) **Field of Classification Search**

CPC .. H04N 9/3111; H04N 9/3123; H04N 9/3138; H04N 9/3155; H04N 9/3158; H04N 9/3161; H04N 9/3164; H04N 9/3182; H04N 9/3185; H04N 9/31–3197; G03B 21/2006; G03B 21/2013; G03B 21/2033; G03B 21/2053; G03B 21/206; G03B 21/147; G03B 21/00–64; G02B 27/01–0189; G02B 2027/0105–0198

See application file for complete search history.

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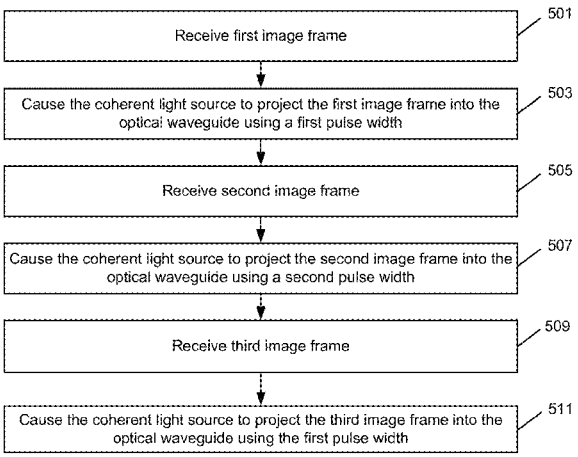
(57) **ABSTRACT**

In an optical system that includes a coherent light source and an optical waveguide, a pulse width used by the optical waveguide to project image frames on a display is changed on a frame-by-frame basis. By changing the pulse width for each image frame, the locations and characteristics of visible interference patterns on the display are changed for each successive image frame. Changing the interference patterns for each image frame may result in the interference patterns being less detectable to a viewer. The change in pulse width for each image frame may be fixed or dynamic, and may be made in response to interference patterns being detected on the display.

20 Claims, 7 Drawing Sheets



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H01S 3/00	(2006.01)
H01S 3/06	(2006.01)
G02B 27/00	(2006.01)
G03B 21/20	(2006.01)

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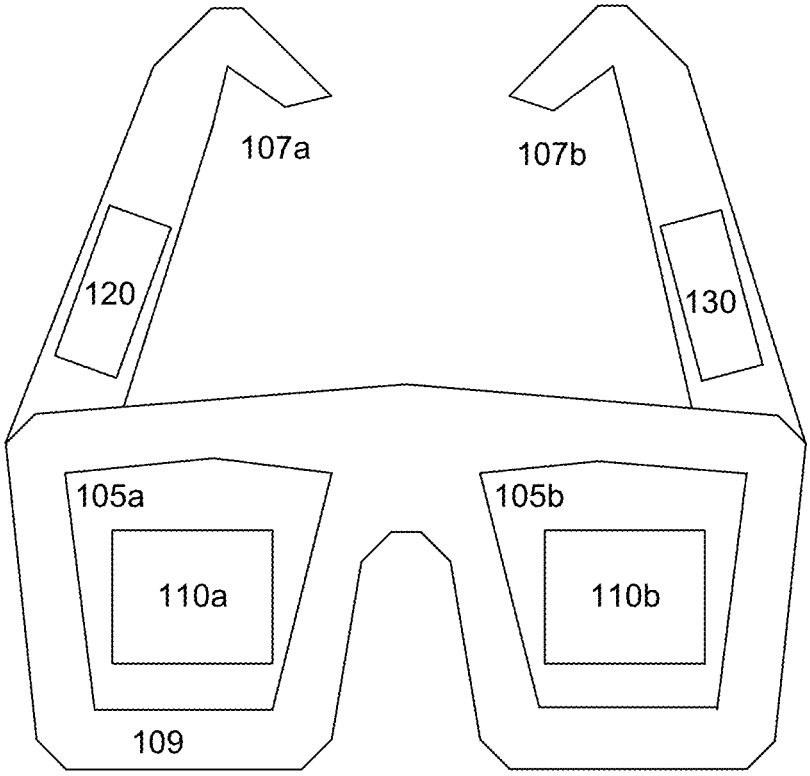


100

FIG. 1

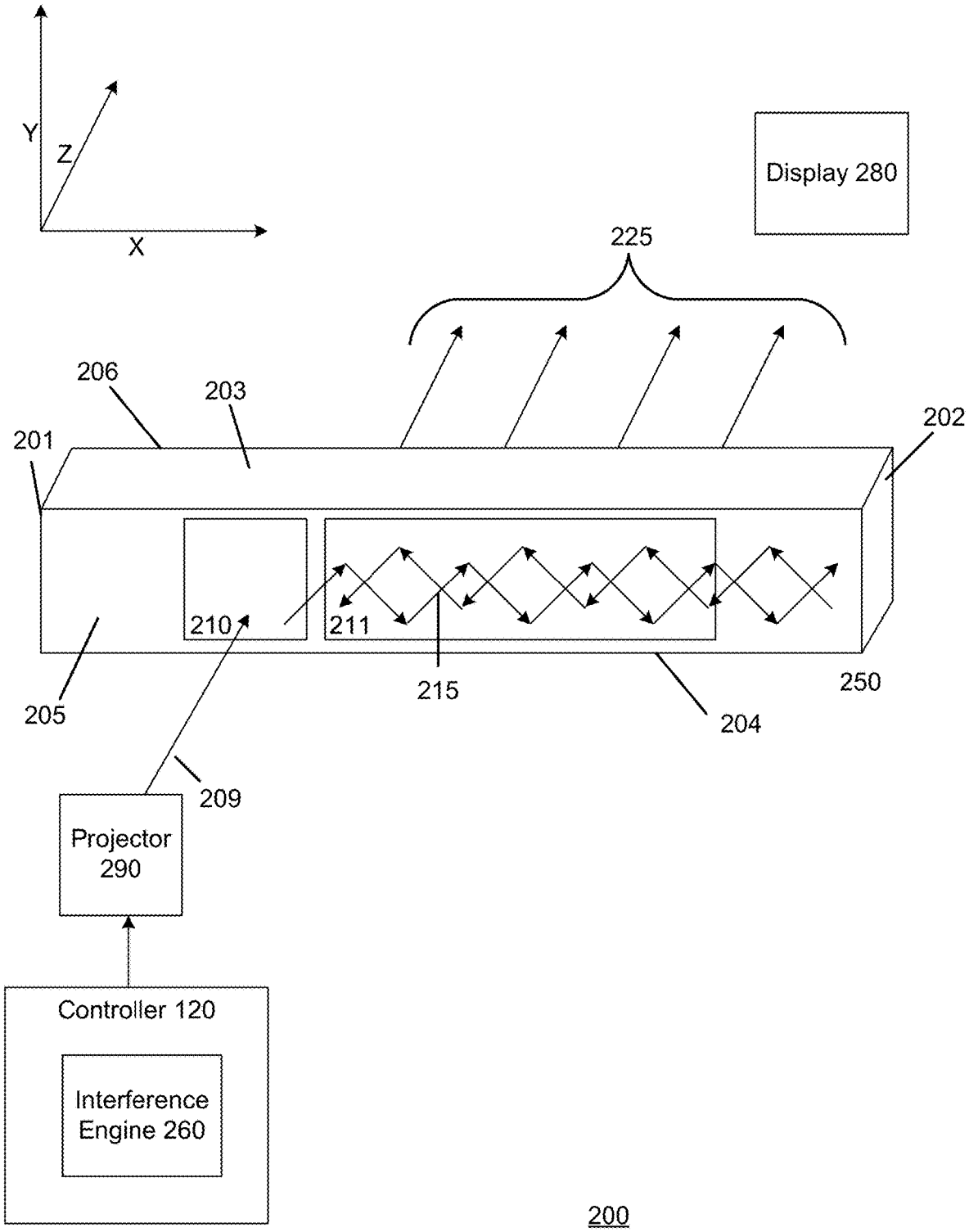
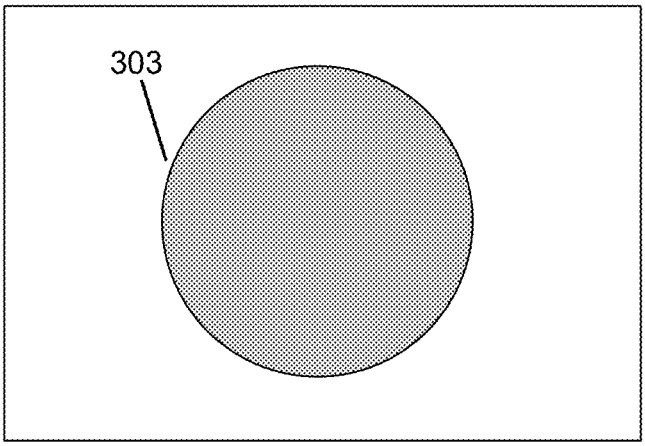
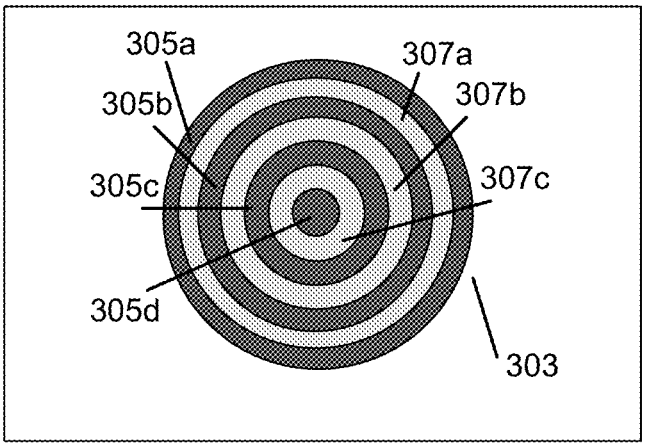

Y
Z
X
Display 280
225
206
203
201
202
210
211
215
205
204
250
209
Projector 290
Controller 120
Interference Engine 260
200

FIG. 2



300a



300b

300

FIG. 3

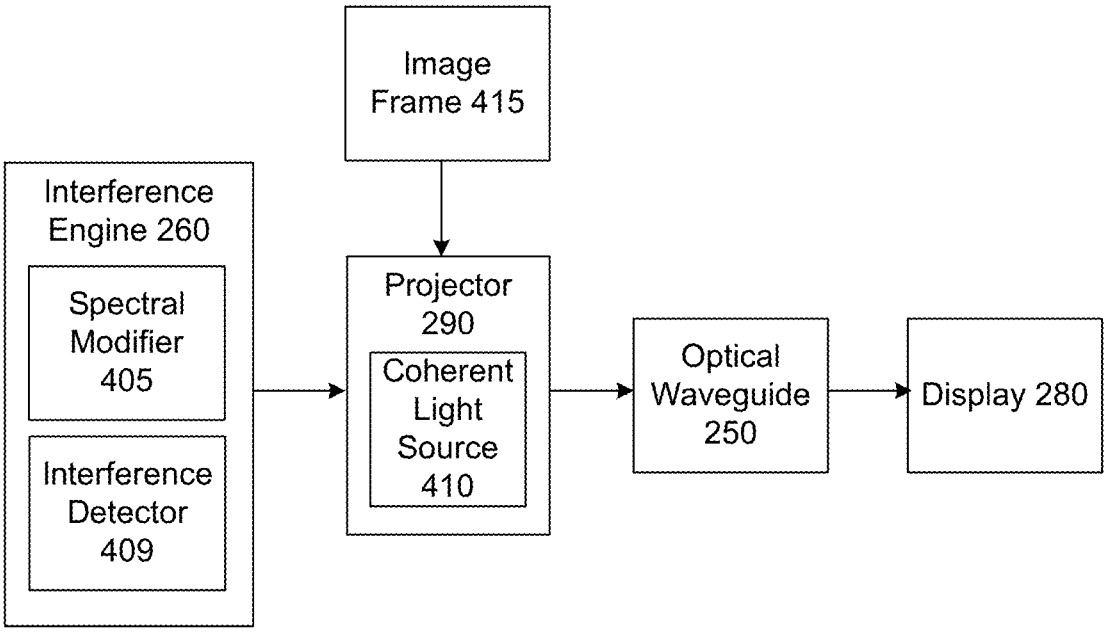


Image Frame 415
Interference Engine 260
Spectral Modifier 405
Interference Detector 409
Projector 290
Coherent Light Source 410
Optical Waveguide 250
Display 280

400

FIG. 4

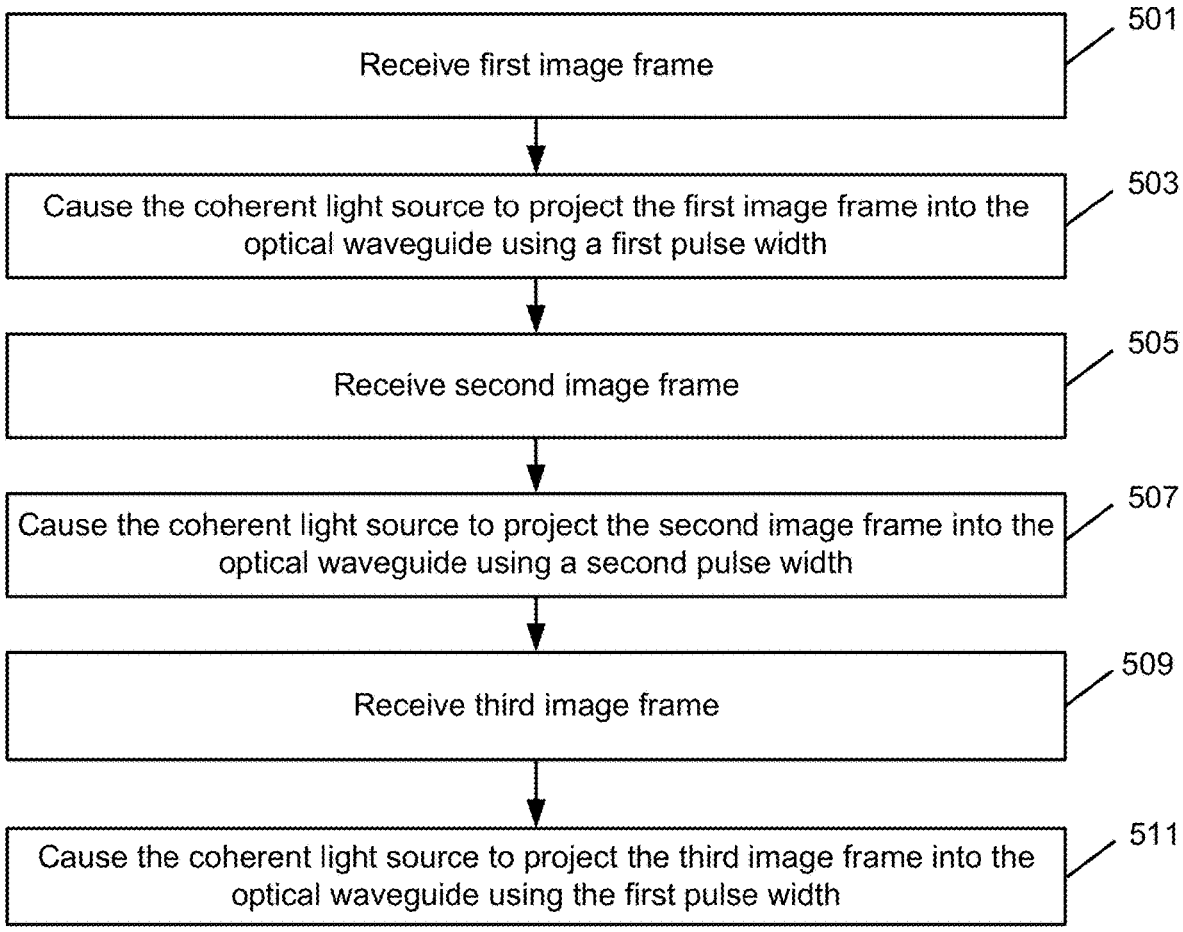

Receive first image frame
501
Cause the coherent light source to project the first image frame into the optical waveguide using a first pulse width
503
Receive second image frame
505
Cause the coherent light source to project the second image frame into the optical waveguide using a second pulse width
507
Receive third image frame
509
Cause the coherent light source to project the third image frame into the optical waveguide using the first pulse width
511
500

FIG. 5

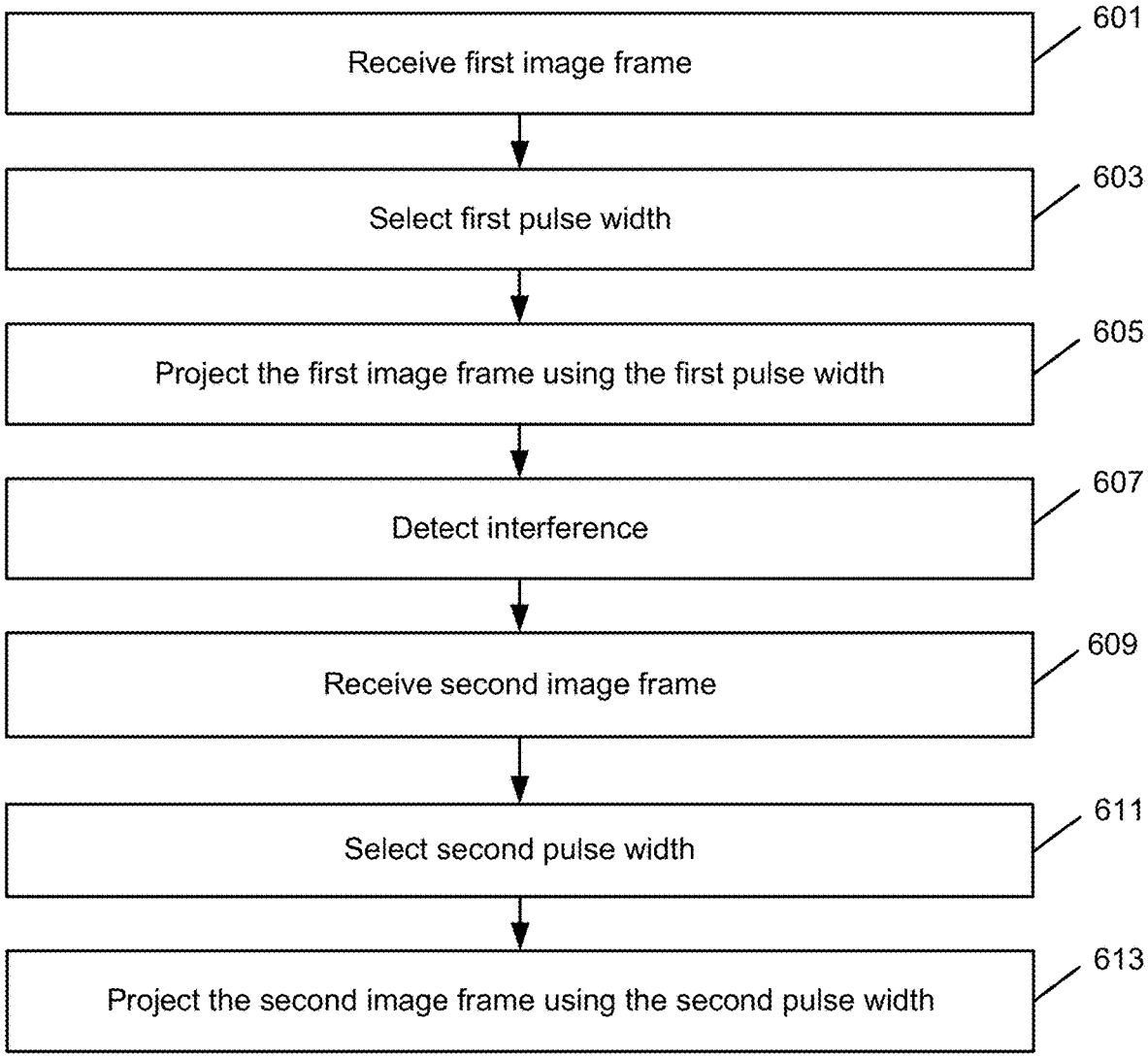

Receive first image frame
601
Select first pulse width
603
Project the first image frame using the first pulse width
605
Detect interference
607
Receive second image frame
609
Select second pulse width
611
Project the second image frame using the second pulse width
613
600

FIG. 6

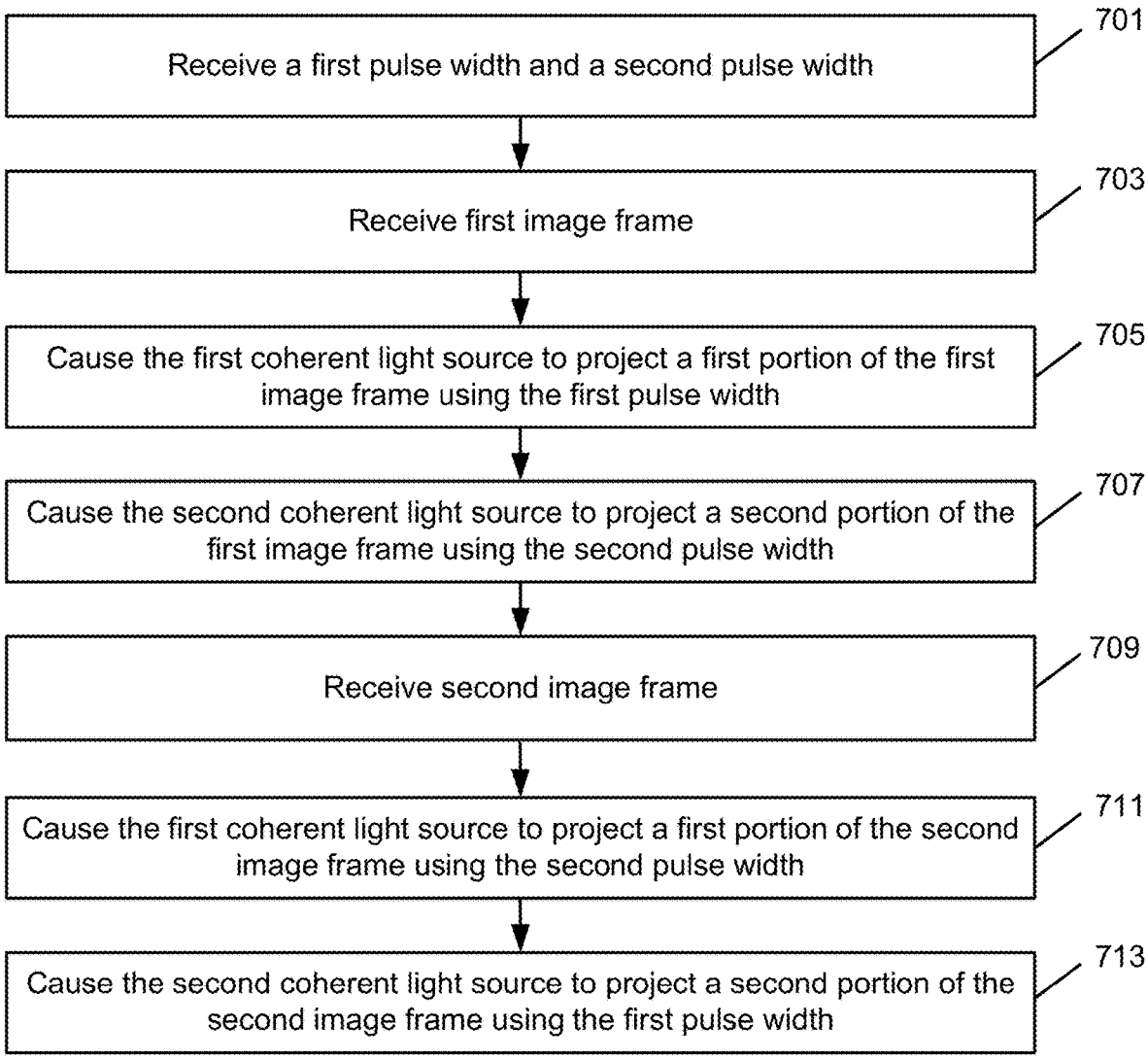

Receive a first pulse width and a second pulse width
701
Receive first image frame
703
Cause the first coherent light source to project a first portion of the first image frame using the first pulse width
705
Cause the second coherent light source to project a second portion of the first image frame using the second pulse width
707
Receive second image frame
709
Cause the first coherent light source to project a first portion of the second image frame using the second pulse width
711
Cause the second coherent light source to project a second portion of the second image frame using the first pulse width
713
700

FIG. 7

CHANGING PULSE WIDTH TO REDUCE VISIBLE INTERFERENCE

BACKGROUND

Optical waveguides can be used to expand or replicate the exit pupil of an imaging system in one or two dimensions. Typically, light from the exit pupil of the imaging system is received in the waveguide through an entrance or in-coupling, and travels through the waveguide in a direction, while some of the light exits a grating structure of the waveguide to a display or the eye of a user. The remaining light that does not exit the grating structure may reflect off of the internal surfaces of the waveguide before finally exiting through the grating structure or some other part of the waveguide.

One issue with current waveguide-based exit pupil expanders is they may result in visible interference when used with coherent light sources. Coherent light sources are light sources containing a narrow range of frequencies. Coherent light sources when split into multiple paths by the waveguide will generally interfere with themselves when received by the display if the difference in optical path length traversed by each optical path of the light is less than a coherence length associated with the coherent light source. An example of a coherent light source is a laser.

Coherent light sources have several advantages over current LCoS (liquid crystal on silicon) based imaging systems, especially when used in head mounted display systems. For example, they have high sequential contrast ratios, lower weight and size, and can be adjusted to compensate for non-uniformities of the waveguide. Accordingly, there is a need to reduce the visible interference associated with coherent light sources and optical waveguides.

SUMMARY

In an optical system that includes a coherent light source and an optical waveguide, a pulse width used by the optical waveguide to project image frames on a display is changed on a frame-by-frame basis. By changing the pulse width for each image frame, the locations and characteristics of visible interference patterns on the display are changed for each successive image frame. Changing the interference patterns for each image frame may result in the interference patterns being less detectable to a viewer. The change in pulse width for each image frame may be fixed or dynamic, and may be made in response to interference patterns being detected on the display. Where the system includes multiple coherent light sources, the pulse widths used by each of the coherent light sources may be similarly changed. The optical system may be incorporated into a head mounted display device or other type of display device that uses coherent light sources.

In an implementation, a system for reducing visible interference associated with coherent light sources is provided. The system includes an optical waveguide, a coherent light source, and an interference engine. The interference engine is configured to receive a first image frame, cause the coherent light source to project the first image frame into the optical waveguide using a first pulse width, receive a second image frame, and cause the coherent light source to project the second image frame into the optical waveguide using a second pulse width, wherein the first pulse width is different than the second pulse width.

In an implementation, a method for reducing visible interference associated with coherent light sources is provided. The method may include receiving a first image frame at a computing device, selecting a first pulse width by the computing device, projecting the first image frame using the first pulse width by the computing device, receiving a second image frame at the computing device, selecting a second pulse width by the computing device, wherein the second pulse width is different than the first pulse width, and projecting the second image frame using the second pulse width by the computing device.

In an implementation, a system for reducing visible interference associated with coherent light sources is provided. The system may include an optical waveguide, a first coherent light source, a second coherent light source, and an interference engine. The interference engine may be configured to: select a first pulse width and a second pulse width, wherein the first pulse width is different than the second pulse width; receive a first image frame; cause the first coherent light source to project a first portion of the first image frame into the optical waveguide using the first pulse width; cause the second coherent light source to project a second portion of the first image frame into the optical waveguide using the second pulse width; receive a second image frame; cause the first coherent light source to project a first portion of the second image frame into the optical waveguide using the second pulse width; and cause the second coherent light source to project a second portion of the second image frame into the optical waveguide using the first pulse width.

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing summary, as well as the following detailed description of illustrative embodiments, is better understood when read in conjunction with the appended drawings. For the purpose of illustrating the embodiments, there is shown in the drawings example constructions of the embodiments; however, the embodiments are not limited to the specific methods and instrumentalities disclosed. In the drawings:

FIG. **1** is an illustration of an exemplary head mounted display device;

FIG. **2** is an illustration of an exemplary near-eye display system;

FIG. **3** is an illustration of an exemplary interference pattern;

FIG. **4** is an illustration of an exemplary interference engine;

FIG. **5** is an operational flow of an implementation of a method for reducing visible interference in an HMD device using one or more coherent light sources;

FIG. **6** is an operational flow of an implementation of a method for reducing visible interference in an HMD device using one or more coherent light sources; and

FIG. **7** is an operational flow of an implementation of a method for reducing visible interference in an HMD device using two or more coherent light sources.

DETAILED DESCRIPTION

FIG. **1** is an illustration of an example head mounted display ("HMD") device **100**. In an implementation, the HMD device **100** is a pair of glasses. The HMD device **100** includes lenses **105***a* and **105***b* arranged within a frame **109**.

The frame **109** is connected to a pair of temples **107***a* and **107***b*. Arranged between each of the lenses **105** and a wearer's eyes is a near-eye display system **110**. The system **110***a* is arranged in front of a right eye and behind the lens **105***a*. The system **110***a* is arranged in front of a left eye and behind the lens **105***a*. The HMD device **100** also includes a controller **120** and one or more sensors **130**. The controller **120** may be a microcomputer operatively coupled to both near-eye display systems **110***a* and **110***b* and to the sensors **130**. Other types of controllers **120** may be used.

The sensors **130** may be arranged in any suitable location on the HMD device **100**. They may include a gyroscope or other inertial sensors, a global-positioning system (GPS) receiver, and/or a barometric pressure sensor configured for altimetry. The sensors **130** may provide data on the wearer's location or orientation. From the integrated responses of the sensors **130**, the controller **120** may track the movement of the HMD device **100** within the wearer's environment.

In some implementations, the sensors **130** may include an eye tracker that is configured to detect an ocular state of the wearer of the HMD device **100**. The eye tracker may locate a line of sight of the wearer, measure an extent of iris closure, etc. If two eye trackers are included, one for each eye, then the two may be used together to determine the wearer's focal plane based on the point of convergence of the lines of sight of the wearer's left and right eyes. This information may be used by the controller **120** for placement of a computer-generated image frame. The image frame may be a frame of a video, or the output of a computer application such as a video game, for example.

In some implementations, each of the near-eye display systems **110***a* and **110***b* may be at least partly transparent, to provide a substantially unobstructed field of view in which the wearer can directly observe their physical surroundings. Each of the near-eye display systems **110***a* and **110***b* may be configured to present, in the same field of view, a computer-generated image frame.

The controller **120** may control the internal componentry of the near-eye display systems **110***a* and **110***b* to form the desired image frame. In an implementation, the controller **120** may cause the near-eye display systems **110***a* and **110***b* to display approximately the same image frame concurrently, so that the wearer's right and left eyes receive the same image frame at approximately the same time. In other implementations, the near-eye display systems **110***a* and **110***b* may project somewhat different image frames concurrently, so that the wearer perceives a stereoscopic, i.e., three-dimensional, image frame.

In some implementations, the computer-generated image frames and various real images of objects sighted through the near-eye display systems **110***a* and **110***b* may occupy different focal planes. Accordingly, the wearer observing a real-world object may shift their corneal focus to resolve the image frame. In other implementations, the image frame and at least one real image may share a common focal plane.

In the HMD device **100**, each of the near-eye display systems **110***a* and **110***b* may also be configured to acquire video of the surroundings sighted by the wearer. The video may include depth video and may be used to establish the wearer's location, what the wearer sees, etc. The video acquired by each near-eye display system **110***a*, **110***b* may be received by the controller **120**, and the controller **120** may be configured to process the video received. To this end, the HMD device **100** may include a camera. The optical axis of the camera may be aligned parallel to a line of sight of the wearer of the HMD device **100**, such that the camera acquires video of the external imagery sighted by the wearer.

As the HMD device **100** may include two near-eye display systems—one for each eye—it may also include two cameras. More generally, the nature and number of the cameras may differ in the various embodiments of this disclosure. One or more cameras may be configured to provide video from which a time-resolved sequence of three-dimensional depth maps is obtained via downstream processing.

No aspect of FIG. **1** is intended to be limiting in any sense, for numerous variants are contemplated as well. In some embodiments, for example, a vision system separate from the HMD device **100** may be used to acquire video of what the wearer sees. In some embodiments, a single near-eye display system extending over both eyes may be used instead of the dual monocular near-eye display systems **110***a* and **110***b* shown in FIG. **1**.

The HMD device **100** may be used to support a virtual-reality ("VR") or augmented-reality ("AR") environment for one or more participants. A realistic AR experience may be achieved with each AR participant viewing their environment naturally, through passive optics of the HMD device **100**. Computer-generated imagery may be projected into the same field of view in which the real-world imagery is received. Imagery from both sources may appear to share the same physical space.

The controller **120** in the HMD device **100** may be configured to run one or more computer programs that support the VR or AR environment. In some implementations, one or more computer programs may run on the controller **120** of the HMD device **100**, and others may run on an external computer accessible to the HMD device **100** via one or more wired or wireless communication links. Accordingly, the HMD device **100** may include suitable wireless componentry, such as Wi-Fi.

FIG. **2** is an illustration of an exemplary near-eye display system **200**. The near-eye display system **200** may be an implementation of one or both of the near-eye display systems **110***a* and **110***b* shown in FIG. **1**. In the example shown, the system **200** includes a projector **290**, an optical waveguide **250**, a controller **120**, and a display **280**.

The projector **290** may be adapted to form an image frame, and to project the image frame through an exit pupil of the projector **290**. Light corresponding to the image frame is shown in the near-eye display system **200** as the light **209**. The projector **290** may be operatively coupled to the controller **120**. The controller **120** may provide suitable control signals that, when received by the projector **290**, cause the desired image frame to be formed.

The optical waveguide **250** may include a plurality of surfaces including a front surface **205**, a rear surface **206**, a top surface **203**, a bottom surface **204**, a left-side surface **201**, and a right-side surface **202**. The optical waveguide **250** may be substantially transparent to light received normal to the front surface **205** in the Z direction. Light received normal to the front surface **205** may pass through the front surface **205** and the rear surface **206** to the display **280**.

The optical waveguide **250** further includes an optical element **210**. The optical element ("OE") **210** may receive the light **209** from an exit pupil of the projector **290**, and may cause a portion of the light **209** to enter the optical waveguide **250** (i.e., in-couple). The portion of the light **209** that enters the optical waveguide **250** is illustrated in the optical waveguide **250** as the light **215**. Depending on the implementation, the OE **210** may be a diffractive OE such as a diffractive grating. Examples of suitable diffractive gratings include surface-relief diffraction gratings ("SRGs") or volumetric gratings. However, other types of OEs may be used, such as mirrors and prisms, for example.

The OE **210** may cause the light **215** to propagate in the X direction towards the right-side surface **202**. In particular, the OE **210** may cause the light **215** to propagate in the X direction by reflecting off of interior surfaces of the optical waveguide **250**.

The optical waveguide **250** may further include an OE **211**. As the light **215** propagates through the optical waveguide **250** and passes through the OE **211**, the OE **211** may allow at least a portion of the light **215** to exit the optical waveguide **250** (i.e., out-couple) through the rear surface **206** as the light **225**. Each ray of the light **225** may leave the rear surface through an exit pupil of the optical waveguide **250**. The light **225** may be received by the display **280**. Like the OE **210**, the OE **211** may be a diffractive coating on the front surface **205** such as an SRG. Other types of diffractive gratings may be used. While shown on the front surface **205**, the OE **211** may also be applied to the rear surface **206**. The number and locations of the exit pupils of the optical waveguide **250** may depend on the properties of the OE **211**.

The portion of the light **215** that does not exit the optical waveguide **250** through an exit pupil may continue in the X direction towards the right-side surface **202**, The light **215** may exit the optical waveguide **250** through the right-side surface **202**, or may be internally reflected back through the optical waveguide **250** towards the left-side surface **201**. The internally reflected light may then be out-coupled by the OE **211**, or may continue to be internally reflected.

As may be appreciated, the light **225** exiting the optical waveguide **250** through the exit pupils of the OE **211** is a pupil expansion of the exit pupil of the projector **290**. Each arrow representing the light **225** may exit through an exit pupil of the optical waveguide **250**.

Typically, the projectors **290** use incoherent light sources, rather than coherent light sources, to generate the light **209** that is used to project the image frame. A coherent light source may be a light source whose output light **209** includes photons that are oscillating in the same direction. This is in contrast with incoherent light sources where the photons may be oscillating in different directions. Examples of coherent light sources include lasers, and examples of incoherent light sources include LED light sources.

While coherent light sources have many advantages over incoherent light sources including higher power output and efficiency, they have one major drawback in that they are susceptible to interference when the total optical path is less than a coherence length of the coherent light source. The length of an optical path of a ray of light is the total distance that the ray of light travels from the projector **290** until it is received by the display **280**, and includes the total distance that the ray travels within the optical waveguide **250** as the light **215**, and the distance that the light travels from the rear surface **206** to the eye **280** as the light **225**.

As described above, because the rays of the light **215** make different numbers of passes through the OE **211** before being out-coupled as the light **225**, there may be many different path lengths for the rays of the light **225** received by the display **280**. Depending on the differences between the lengths of the rays of light **225**, there may either be constructive or destructive interference visible on the display **280**.

For example, FIG. **3** shows an example interference pattern that may be associated with coherent light sources. The image frame **300***a* is an example of an image frame that is projected on the display **280** that includes a circle **303**, The circle **303** is shown with a uniform medium grey color and has no visible interference patterns.

The image frame **300***b* is an example of an image frame of the same circle **303** but with visible interference patterns. In the example shown, the circle **303** includes several rings **305** (i.e., rings **305***a-d*) that are visibly darker than the color of the circle **303** shown in the image frame **300***a*. These rings **305** are areas of constructive interference due to the rays of light being in-phase with each other. The circle also includes several rings **307** (i.e., rings **307***a-c*) that are visibly lighter than the color of circle **303** shown in the image frame **300***a*. These rings **307** are areas of destructive interference due to the rays of light being out-of-phase with each other. The type of interference patterns shown in the image frame **300***b* are known as Newton's rings.

Returning to FIG. **2**, in order to reduce the visible interference due to coherent light sources, the near-eye display system **200** includes an interference engine **260** that effectively changes the output spectra of the coherent light source on a-frame-by-frame basis. Changing the spectral characteristics for each image frame changes the location and/or appearance of the visible interference pattern for the image frames. Because of the high frame used by the near-eye display system **200** (e.g., 120 Hz), the resulting interference patterns become averaged out and less visible to the wearer of the near-eye display system **200**.

As described further below, one way of changing the spectral characteristics of the coherent light source is through pulse width modulation. The interference engine **260** may periodically adjust or change a pulse width used by the coherent light source. In particular, the interference engine **260** may change the pulse width used by the coherent light source for each image frame in a sequence of image frames. Changing the pulse width changes the "effective temperature" of the coherent light source which may change the spectral characteristics of the coherent light source. By changing the pulse width for each image frame, the location and other characteristics of the resulting interference pattern that is visible to the wearer of the near-eye display system **200** is also changed for each image frame.

Because the visible coherence pattern is changed for each image frame, the overall amount of interference that is visible to the wearer of the HMD device **100** is reduced.

Other methods for changing the spectral characteristics of the coherent light source may be used. For example, the interference engine **260** may change the spectral characteristics by changing the pulse shape used by the coherent light source. In another example, the interference engine **260** may change the spectral characteristics by shifting the spectrum associated with the coherent light source. Other methods may be used such as a biasing scheme or by changing a laser cavity optical length, for example.

FIG. **4** is an illustration of an exemplary interference engine **260**. The interference engine **260** includes components such as a spectral modifier **405** and an interference detector **409**. More or fewer components may be supported. The interference engine **260** may be implemented by one or more computing devices such as the HMD device **100**.

The spectral modifier **405** may effectively change the spectral characteristics of a coherent light source **410** to reduce visible inference with respect to an image frame **415** projected on a display **280**. The coherent light source **410** may be a laser and may be part of a projector **290**. In some implementations, the spectral modifier **405** may change the spectral characteristics of the coherent light source **410** for each image frame **415**. For example, the spectral modifier **405** may use first spectral characteristics for a first image frame **415**, and may use second spectral characteristics for a second image frame **415**. The spectral modifier **405** may

use the first spectral characteristics for a third image frame **415**, or may use different spectral characteristics.

The spectral modifier **405** may change the spectral characteristics of the coherent light source **410** by changing a pulse width used by the coherent light source **410**. Depending on the implementation, the spectral modifier **405** may increase or decrease the pulse width of the coherence light source **410** used for successive image frames **415** by approximately one to ten nanoseconds. The amount that the pulse width is changed may be fixed or randomly selected. The amount that the pulse width is changed may set by a user, or may be automatically selected during a calibration phase. Any method or technique for changing a pulse width of a coherent light source **410** may be used.

The spectral modifier **405** may further change the spectral characteristics by shifting a spectrum used by the coherent light source **410**. For example, the spectral modifier **405** may shift the spectrum of the coherent light source **410** by applying a bias current to the coherent light source **410**. The spectrum used by the coherent light source **410** may be shifted by changing the amount of bias current that is applied. Other methods for shifting a spectrum of a coherent light source **410** may be used.

The spectral modifier **405** may further change the spectral characteristics by changing a pulse shape used by the coherent light source **410**. Any method for changing a pulse shape of a coherent light source **410** may be used.

In systems with more than one coherence light source **410**, the spectral modifier **405** may change the spectral characteristics of each of the coherent light sources **410**. For example, the projector **290** may include a first coherent light source **410** that projects blue light, a second coherent light source **410** that projects red light, and third coherent light source **410** that projects green light. For a first image frame **415**, the spectral modifier **405** may cause the first coherent light source **410** to project a portion of the first image frame **415** that corresponds to the blue light using a first pulse width, may cause the second coherent light source **410** to project a portion of the first image frame **415** that corresponds to the red light using the first pulse width, and may cause the third coherent light source **410** to project a portion of the first image frame **415** that corresponds to the green light using the first pulse width.

For a subsequent second image frame **415**, the spectral modifier **405** may change the pulse widths used for each of the first, second, and third coherent light sources **410**. The spectral modifier **405** may use the same pulse widths for each coherent light source **410**, may change the each pulse width by a same amount, or may use a different pulse width for each coherent light source **410**. For example, the spectral modifier **405** may cause the first coherent light source **410** to project a portion of the second image frame **415** that corresponds to the blue light using a second pulse width, may cause the second coherent light source **410** to project a portion of the second image frame **415** that corresponds to the red light using the second pulse width, and may cause the third coherent light source **410** to project a portion of the second image frame **415** that corresponds to the green light using the second pulse width.

In some implementations, the projector **290** may include multiple coherent light sources **410** per light color. For example, the projector **290** may include two coherent light sources **410** for the color red, two coherent light sources **410** for the color blue, and two coherent light sources **410** for the color green. In these implementations, for each light color, the spectral modifier **405** may cause the first coherent light source **410** to use a first pulse width and the second coherent light source **410** to use a second pulse width for a first image frame **415**, and may cause the first coherent light source **410** to use the second pulse width and the second coherent light source **410** to use the first pulse width for a subsequent second image frame **415**. Other combinations of pulse widths may be used.

The interference detector **409** may detect or measure interference in a projected image frame **415**, and may instruct the spectral modifier **405** to change the spectral characteristics of one or more coherent light sources **410** in response to the determination. In some implementations, the interference detector **409** may operate as part of a calibration phase where various image frames **415** are projected onto the display **280** by the coherent light sources **410**. The performance of the coherent light sources **410** may be measured for various metrics such as brightness, contrast level, sharpness, and any interference patterns may be detected. Any method or technique for detecting interference patterns may be used.

The interference detector **409** may instruct the spectral modifier **405** to adjust the spectral characteristics in response to any detected interference patterns. For example, the interference detector **409** may instruct the spectral modifier **405** to change the pulse width used by the coherent light source **410** by some amount for each successive image frame **415**. After making the change, the interference detector **409** may continue to measure the metrics associated with the display **280** to ensure that the change in the spectral characteristics has not resulted in any adverse effects such as a reduction in brightness. If the change in the pulse width results in adverse effects, the interference detector **409** may recommend a smaller change in the pulse width be used for each image frame **415**, for example.

In some implementations, the interference detector **409** may continuously monitor the image frames **415** projected on the display **280** for interference. In response to the detected interference, the interference detector **409** may instruct the spectral modifier **405** to change the pulse width used by the coherent light source **410**. Alternatively or additionally, the interference detector **409** may instruct the spectral modifier **405** to change the pulse shape or shift the spectrum used by the coherent light source **410**.

FIG. **5** is an operational flow of an implementation of a method **500** for reducing visible interference in an HMD device **100** using one or more coherent light sources **410**. The method **500** may be implemented by the interference engine **260**, for example.

At **501**, a first image frame is received. The first image frame **415** may be received by the coherent light source **410**. The coherent light source **410** may be a laser. The first image frame **415** may be an image frame **415** of a video or output of an application currently being viewed and/or used by a wearer of an HMD device **100**. The HMD device **100** may include an optical waveguide **250** and a display **280**.

At **503**, the coherent light source is caused to project the first image frame into the optical waveguide using a first pulse width. The coherent light source **410** may be caused to project the first image frame **415** using the first pulse width by the interference engine **260**.

At **505**, a second image frame is received. The second image frame **415** may be received by the coherent light source **410**. The second image frame **415** may be a next image frame **415** of the video or the output of the application currently being viewed and/or used by the wearer of the HMD device **100**.

At **507**, the coherent light source is caused to project the second image frame into the optical waveguide using a

second pulse width. The coherent light source **410** may be caused to project the second image frame **415** using the second pulse width by the interference engine **260**. The second pulse width may be selected by the interference engine **260** to reduce visible interference on the display **280**. A difference between the first pulse width and the second pulse width may be between one and ten nanoseconds. Depending on the implementation, additional steps may be taken to reduce visible interference such as shifting a spectrum associated with the coherent light source **410** or changing a pulse width shape.

At **509**, a third image frame is received. The third image frame **415** may be received by the coherent light source **410**. The third image frame **415** may be a next image frame **415** of the video or the output of the application currently being viewed and/or used by the wearer of the HMD device **100**.

At **511**, the coherent light source is caused to project the third image frame into the optical waveguide using the first pulse width. The coherent light source **410** may be caused to project the third image frame **415** using the first pulse width by the interference engine **260**. Alternatively, the coherent light source **410** may be caused to project the third image frame **415** using a third pulse width.

FIG. **6** is an operational flow of an implementation of a method **600** for reducing visible interference in an HMD device **100** using one or more coherent light sources **410**. The method **600** may be implemented by the interference engine **260**, for example.

At **601**, a first image frame is received. The first image frame **415** may be received by the coherent light source **410**. The coherent light source **410** may be a laser. The first image frame **415** may be an image frame **415** of a video or output of an application currently being viewed and/or used by a wearer of an HMD device **100**. The HMD device **100** may include an optical waveguide **250** and a display **280**.

At **603**, a first pulse width is selected. The first pulse width may be selected by the spectral modifier **405**.

At **605**, the first image frame is projected using the first pulse width. The first image frame **415** may be projected by the coherent light source **410** into the optical waveguide **250**.

At **607**, interference is detected. The interference may be visible interference that is detected by the interference detector **409** in the projected first image frame **415**. The visible interference may be associated with the use of the coherent light source **410**. Any method for detecting visible interference may be used. Depending on the implementation, the interference may be detected as part of a calibration phase associated with the HMD device **100**.

At **609**, a second image frame is received. The second image frame **415** may be received by the coherent light source **410**. The second image frame **415** may be a next image frame of the video or the output of the application currently being viewed and/or used by the wearer of the HMD device **100**.

At **611**, a second pulse width is selected. The second pulse width may be selected by the spectral modifier **405**. The second pulse width may be selected based on the detected interference to effectively change the spectral characteristics of the coherent light source **410**. By changing the spectral characteristics the location and characteristics of the detected interference may be changed resulting in the interference being overall less visible to the user. Other methods for changing the spectral characteristics of the coherent light source **410** may be used, including shifting a spectrum of the coherent light source **410** and changing a pulse shape of the coherent light source **410**.

At **613**, the second image from is projected using the second pulse width. The second image frame **415** may be projected by the coherent light source **410** into the optical waveguide **250**.

FIG. **7** is an operational flow of an implementation of a method **700** for reducing visible interference in an HMD device **100** using two or more coherent light sources **410**. The method **700** may be implemented by the interference engine **260**, for example.

At **701**, a first pulse width and a second pulse width are received. The first pulse width and the second pulse width may be received by the projector **290** from the spectral modifier **405**. The first and second pulse widths may have been selected to reduce visible interference in the HMD device **100** without unduly harming characteristics of the HMD device **100** such as brightness and contrast. Depending on the implementation, a difference between the first pulse width and the second pulse width may be between one and ten nanoseconds.

The first and second pulse widths may be received for a first coherent light source **410** and a second coherent light source **410**. The first coherent light source **410** and the second coherent light source **410** may be associated with the same or different color of light. The first coherent light source **410** and the second coherent light source **410** may be lasers.

At **703**, a first image frame is received. The first image frame **415** may be received by the first coherent light source **410** and the second coherent light source **410**. The first image frame **415** may have a first portion and a second portion. In implementations where the first coherent light source **410** and the second coherent light source **410** are the same color of light, the first portion of the first image frame **415** may correspond to even lines of the first image frame **415** and the second portion of the first image frame **415** may correspond to odd lines of the first image frame **415**. In implementations where the first coherent light source **410** and the second coherent light source **410** correspond to different colors, the first portion of the first image frame **415** may correspond to blue colors of the first image frame **415** and the second portion of the first image frame **415** may correspond to red colors of the first image frame **415**. Other configurations and colors may be supported.

At **705**, the first coherent light source is caused to project the first portion of the first image frame using the first pulse width. The first coherent light source **410** may be caused to project the first portion of the first image frame **415** using the first pulse width by the interference engine **260**. The first portion of the first image frame **415** may be projected into an optical waveguide **250** of the HMD device **100**.

At **707**, the second coherent light source is caused to project the second portion of the first image frame using the second pulse width. The second coherent light source **410** may be caused to project the second portion of the first image frame **415** using the second pulse width by the interference engine **260**. The second portion of the first image frame **415** may be projected into the optical waveguide **250** of the HMD device **100**.

At **709**, a second image frame is received. The second image frame **415** may be received by the first coherent light source **410** and the second coherent light source **410**. The second image frame **415** may have a first portion and a second portion.

At **711**, the first coherent light source is caused to project the first portion of the second image frame using the second pulse width. The first coherent light source **410** may be

caused to project the first portion of the second image frame **415** using the second pulse width by the interference engine **260**.

At **713**, the second coherent light source is caused to project the second portion of the second image frame using the first pulse width. The second coherent light source **410** may be caused to project the second portion of the second image frame **415** using the first pulse width by the interference engine **260**.

It should be understood that the various techniques described herein may be implemented in connection with hardware components or software components or, where appropriate, with a combination of both. Illustrative types of hardware components that can be used include Field-programmable Gate Arrays (FPGAs), Application-specific Integrated Circuits (ASICs), Application-specific Standard Products (ASSPs), System-on-a-chip systems (SOCs), Complex Programmable Logic Devices (CPLDs), etc. The methods and apparatus of the presently disclosed subject matter, or certain aspects or portions thereof, may take the form of program code (i.e., instructions) embodied in tangible media, such as floppy diskettes, CD-ROMs, hard drives, or any other machine-readable storage medium where, when the program code is loaded into and executed by a machine, such as a computer, the machine becomes an apparatus for practicing the presently disclosed subject matter.

In an implementation, a system for reducing visible interference associated with coherent light sources is provided. The system includes: an optical waveguide; a coherent light source; and an interference engine. The interference engine is configured to: receive a first image frame; cause the coherent light source to project the first image frame into the optical waveguide using a first pulse width; receive a second image frame; and cause the coherent light source to project the second image frame into the optical waveguide using a second pulse width, wherein the first pulse width is different than the second pulse width.

Implementations may include some or all of the following features. The interference engine may be further configured to select a difference between the first pulse width and the second pulse width. The coherent light source may be a laser. The system may be part of a head mounted display device. The interference engine may be further configured to detect interference in the projected first image frame, and in response to the detection, cause the coherent light source to project the second image frame into the optical waveguide using the second pulse width. The interference engine may be further configured to: receive a third image frame; and cause the coherent light source to project the third image frame into the optical waveguide using the first pulse width.

In an implementation, a method for reducing visible interference associated with coherent light sources is provided. The method may include: receiving a first image frame at a computing device; selecting a first pulse width by the computing device; projecting the first image frame using the first pulse width by the computing device; receiving a second image frame at the computing device; selecting a second pulse width by the computing device, wherein the second pulse width is different than the first pulse width; and projecting the second image frame using the second pulse width by the computing device.

Implementations may include some or all of the following features. The method may include detecting interference in the first image frame, and selecting the second pulse width based on the detected interference. The computing device may include a coherent light source, and projecting the first image frame using the first pulse width by the computing device may include projecting the first image frame using the first pulse width by the coherent light source. The method may further include shifting a spectrum associated with the coherent light source. The coherent light source may be a laser. The computing device may include a first coherent light source and a second coherent light source, and projecting the first image frame using the first pulse width may include: projecting a first portion of the first image frame by the first coherent light source using the first pulse width; and projecting a second portion of the first image frame by the second coherent light source using the first pulse width. Projecting the second image frame using the second pulse width may include: projecting a first portion of the second image frame by the first coherent light source using the second pulse width; and projecting a second portion of the second image frame by the second coherent light source using the second pulse width. The computing device may be part of a head mounted display device. The method may include: receiving a third image frame at the computing device; selecting the first pulse width by the computing device; and projecting the third image frame using the first pulse width by the computing device.

In an implementation, a system for reducing visible interference associated with coherent light sources is provided. The system may include: an optical waveguide; a first coherent light source; a second coherent light source; and an interference engine. The interference engine may be configured to: select a first pulse width and a second pulse width, wherein the first pulse width is different than the second pulse width; receive a first image frame; cause the first coherent light source to project a first portion of the first image frame into the optical waveguide using the first pulse width; cause the second coherent light source to project a second portion of the first image frame into the optical waveguide using the second pulse width; receive a second image frame; cause the first coherent light source to project a first portion of the second image frame into the optical waveguide using the second pulse width; and cause the second coherent light source to project a second portion of the second image frame into the optical waveguide using the first pulse width.

Implementations may include some or all of the following features. The interference engine may be further configured to: receive a third image frame; cause the first coherent light source to project a first portion of the third image frame into the optical waveguide using the first pulse width; and cause the second coherent light source to project a second portion of the third image frame into the optical waveguide using the second pulse width. The system may be part of a head mounted display device. The first coherent light source may be a laser. The first coherent light source may be associated with a first color of light, and the second coherent light source may be associated with a second color of light.

Although the subject matter has been described in language specific to structural features and/or methodological acts, it is to be understood that the subject matter defined in the appended claims is not necessarily limited to the specific features or acts described above. Rather, the specific features and acts described above are disclosed as example forms of implementing the claims.

What is claimed:

1. A system for reducing visible interference associated with coherent light sources, the system comprising:

an optical waveguide;

a coherent light source; and

an interference engine configured to:

receive a first image frame;

cause the coherent light source to project the first image frame into the optical waveguide using a first pulse width;

detecting an interference pattern in the first image frame;

receive a second image frame; and

cause the coherent light source to project the second image frame into the optical waveguide using a second pulse width, wherein the first pulse width is different than the second pulse width and the difference between the first pulse width and the second pulse width is selected based on the interference pattern detected in the first image.

2. The system of claim **1**, wherein the interference engine is further configured to select the difference between the first pulse width and the second pulse width based on a measured contrast level of the interference pattern.

3. The system of claim **1**, wherein the coherent light source comprises a laser.

4. The system of claim **1**, wherein the system is part of a head mounted display device.

5. The system of claim **1**, wherein the interference engine is further configured to detect interference in the projected first image frame, and in response to the detection, cause the coherent light source to change pulse width used by the coherent light source by a predetermined amount for each successive image frame.

6. The system of claim **1**, wherein the interference engine is further configured to:

receive a third image frame; and

cause the coherent light source to project the third image frame into the optical waveguide using the first pulse width.

7. A method for reducing visible interference associated with coherent light sources, the method comprising:

receiving a first image frame at a computing device;

selecting a first pulse width by the computing device;

projecting the first image frame using the first pulse width by the computing device;

receiving a second image frame at the computing device;

selecting a second pulse width by the computing device, wherein the second pulse width is different than the first pulse width and the difference between the first pulse width and the second pulse width is selected based on an interference pattern in the first image; and

projecting the second image frame using the second pulse width by the computing device.

8. The method of claim **7**, further comprising detecting interference in the first image frame, and in response to the detection, causing the coherent light source to change pulse width used by the coherent light source by a predetermined amount for each successive image frame.

9. The method of claim **7**, wherein the computing device comprises a coherent light source, and projecting the first image frame using the first pulse width by the computing device comprises projecting the first image frame using the first pulse width by the coherent light source.

10. The method of claim **9**, further comprising shifting a spectrum associated with the coherent light source.

11. The method of claim **9**, further comprising changing a pulse shape associated with the coherent light source.

12. The method of claim **7**, wherein the computing device comprises a first coherent light source and a second coherent light source, and projecting the first image frame using the first pulse width comprises:

projecting a first portion of the first image frame by the first coherent light source using the first pulse width; and

projecting a second portion of the first image frame by the second coherent light source using the first pulse width.

13. The method of claim **12**, wherein projecting the second image frame using the second pulse width comprises:

projecting a first portion of the second image frame by the first coherent light source using the second pulse width; and

projecting a second portion of the second image frame by the second coherent light source using the second pulse width.

14. The method of claim **12**, wherein the computing device is part of a head mounted display device.

15. The method of claim **7**, further comprising:

receiving a third image frame at the computing device;

selecting the first pulse width by the computing device; and

projecting the third image frame using the first pulse width by the computing device.

16. A system for reducing visible interference associated with coherent light sources, the system comprising:

an optical waveguide;

a first coherent light source;

a second coherent light source; and

an interference engine configured to:

select a first pulse width;

receive a first image frame;

cause the first coherent light source to project a first portion of the first image frame into the optical waveguide using the first pulse width;

detect an interference pattern in the first image frame

select a second pulse width based on an interference pattern, the second pulse width being different than the first pulse width and the difference between the first pulse width and the second pulse width based on a measured contrast level of the interference pattern;

cause the second coherent light source to project a second portion of the first image frame into the optical waveguide using the second pulse width;

receive a second image frame;

cause the first coherent light source to project a first portion of the second image frame into the optical waveguide using the second pulse width; and

cause the second coherent light source to project a second portion of the second image frame into the optical waveguide using the first pulse width.

17. The system of claim **16**, wherein the interference engine is further configured to:

receive a third image frame;

cause the first coherent light source to project a first portion of the third image frame into the optical waveguide using the first pulse width; and

cause the second coherent light source to project a second portion of the third image frame into the optical waveguide using the second pulse width.

18. The system of claim **16**, wherein the system is part of a head mounted display device.

19. The system of claim **16**, wherein the first coherent light source comprises a laser.

20. The system of claim **16**, wherein the first coherent light source is associated with a first color of light, and the second coherent light source is associated with a second color of light.

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